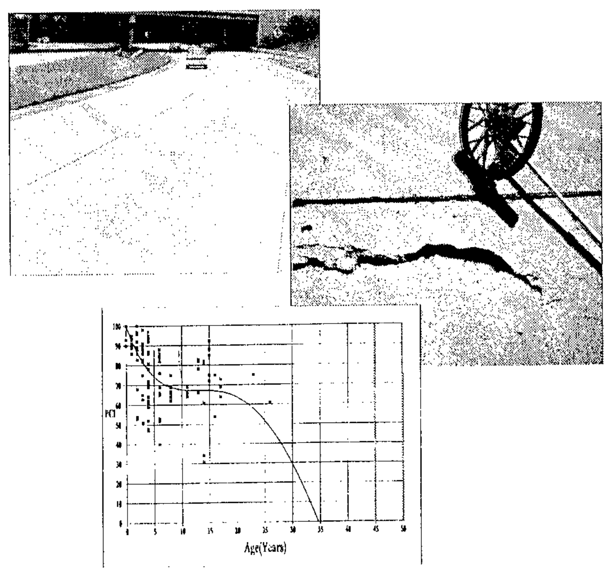
SD97-05-F

PB98-167430

SD Department of Transportation
Office of Research



Statistical Methods for Pavement Performance Curve Building, Historical Analysis, Data Sampling and Storage

Study SD97-05
Final Report
Appendix D

Prepared by:

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Providing engineering solutions to improve pavement performance

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August 1998

APPENDIX D

TECHNICAL MEMORANDUM

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Appendix D: Technical Memorandum

D.0 Technical Memorandum

D.1 Introduction

The technical memorandum is intended to discuss the detailed procedure required for carrying out the statistical analyses of historical pavement condition data for building pavement performance curves. This chapter assumes the availability of the historical data in a spreadsheet format (Microsoft® Excel) that has been retrieved from the master (pavement management system) database.

D.2 Typical Pavement Condition Data

The database contains pavement condition data for each pavement section identified by the section number, the beginning MRM, and the beginning mileage number. Data files (spreadsheets/*.xls) are created for individual pavement families identified by their pavement type. Figure D.1 shows parts of a typical database, in this case for the FD (full depth asphalt), for the AONC (asphalt on concrete), and for the TKSJ (thick short jointed concrete) pavement families.

Apart from the inventory data (FROM_ROAD, BEG_MRM, BEG_MILEAG, COUNTY_NO, HIGH_REG, AREA_CODE, FUNC_CLASS, and ELEM_ID) and the traffic data (CUR_ADT, PCT_TRUCK, and ESALS_FLEX), the database contains pavement condition data, along with the pavement flag and pavement type, for each year of pavement condition survey. The database available for this project contains data collected for the years 1995, 1996, and 1997. The pavement condition data are measured in terms of individual pavement distress, on a scale of 0.00 to 5.00, and hence it is different for the flexible pavement families and the rigid pavement families.

D.3 Data Familiarization and Data Censorship

The objective of data familiarization is to understand the data collection methods used and then to visualize the trend exhibited by dependant variables. This helps in understanding the nature of various pavement families, their relevant distresses, and the scale of the distress index that, in this case, decreases with deterioration. At the network level this process also helps in establishing the geographical location of individual pavement sections along with their functional classification and their relative importance in terms of traffic loads. At this stage it is also important to get familiar with the terminology used for identifying various pavement types and relevant pavement flags.

The database may also contain some errors that do not truly represent the actual pavement conditions. Hence, before carrying out the actual statistical analyses it is important to filter out or correct the corrupted data. This procedure is referred to as Data Censorship. The errors occurring in the pavement condition database can be classified into two broad categories – errors due to improper field data and errors due to improper pavement family transitions.

FULL DEPTH ASPHALT PAVEMENT FAMILY: TYPICAL SECTION INFORMATION

	FROM_ROAD	BEGIN_MRM	BEG_MILEAG	CUR_ADT	PCT_TRUCK	ESALS_FLEX	97TRAN-CK	97FATG-CK	97PTCHDT	97BLK-CK	97RUT-DP	97ROUGH	97PAVFLG	97PAVTYP	97COMMENT
1	1 012	NON-DESCRIPT	343.04	4388	16.1	247	3.80	3.80	6.00	6.00	6.00	4.80	A	FD	
	1 012	012 319.00+00.266	319.22	2775	12.5	124	4.40	5.00	5.00	5.00	4.65	4.80	A	FD	
	1 012	320.00	320.00	2775	12.5	124	4.80	5.00	5.00	5.00	5.00	4.77	A	FD	
	1 012	321.00	321.00	2775	12.5	124	4.40	5.00	5.00	5.00	5.00	4.67	A	FD	
	1 012	322.00	322.00	2775	12.5	124	4.40	5.00	5.00	5.00	5.00	4.62	A	FD	
	1 012	323.00	323.00	2593	12.5	116	4.80	5.00	5.00	5.00	5.00	4.85	A	FD	
	1 012	324.00	324.00	2759	12.5	123	4.80	5.00	5.00	5.00	5.00	4.83	A	FD	
	1 012	327.00	327.00	2525	12.5	113	4.80	4.60	5.00	5.00	5.00	4.77	A	FD	
	1 012	328.00	328.00	2525	12.5	113	4.40	5.00	5.00	5.00	5.00	4.60	A	FD	
	1 012	329.00	329.00	2525	12.5	113	4.80	5.00	5.00	5.00	4.65	4.67	A	FD	
	1 012	330.00	330.00	2525	12.5	113	4.80	3.90	1.90	5.00	4.65	4.58	A	FD	
	1 012	331.00	331.00	2584	12.5	116	2.80	5.00	5.00	5.00	5.00	4.83	A	FD	
	1 012	332.00	332.00	2560	12.5	115	4.40	5.00	5.00	5.00	5.00	4.70	A	FD	
	1 014 EL	011.00	011.00	2942	6.2	107	3.50	4.60	5.00	5.00	5.00	4.60	F	FD	
	1 014 WL	011.00	011.00	2942	6.2	107	3.50	4.60	5.00	5.00	5.00	4.50	F	FD	
	1 015	015 149.00+00.861	149.00	907	17.8	51	4.50	4.60	5.00	4.30	5.00	4.58	A	FD	
	1 015	150.00	150.00	907	17.8	51	4.60	4.60	5.00	4.30	5.00	4.82	A	FD	
2	1 016A	NON-DESCRIPT	086.33	721	8.3	28	4.80	4.80	6.00	6.00	4.65	4.00	F	FD	BLACK HILLS DEFAULT ROUGHNESS
	1 018	254.00	254.00	1569	15.9	69	2.80	4.20	4.20	5.00	4.30	3.70	A	FD	
	1 018	255.00	255.00	1569	15.9	69	4.40	4.20	5.00	5.00	3.90	4.30	A	FD	
	1 018	256.00	256.00	1569	15.9	69	3.50	4.20	5.00	5.00	3.50	3.55	A	FD	
	1 018	257.00	257.00	1569	15.9	69	3.50	4.20	5.00	5.00	3.90	3.50	A	FD	
	1 018	258.00	258.00	1569	15.9	69	3.50	4.20	5.00	5.00	3.90	3.75	A	FD	
	1 018	259.00	259.00	1569	15.9	69	3.50	4.20	5.00	5.00	3.50	3.65	A	FD	
	1 018	260.00	260.00	1569	15.9	69	3.50	4.60	5.00	5.00	3.90	4.15	A	FD	
	1 018	018 260.00+00.500	260.00	1569	15.9	69	3.50	4.60	5.00	5.00	4.30	4.20	A	FD	
	1 018	261.00	261.00	1569	15.9	69	3.50	4.60	5.00	5.00	3.90	3.60	A	FD	
	1 018	263.00	263.00	1365	16.5	77	4.40	4.60	5.00	5.00	4.30	4.50	A	FD	
	1 018	263.33	263.33	1111	17.9	63	4.80	3.80	5.00	5.00	4.65	4.56	A	FD	
	1 018	018 263.34+00.226	263.34	1064	18.0	61	4.80	3.80	5.00	5.00	4.65	4.35	A	FD	
	1 018	274.00	274.00	1519	18.9	85	0.00	3.60	4.60	3.80	4.65	2.60	F	FD	
	1 018	018 274.00+00.250	274.00	1519	18.9	85	0.00	2.30	3.60	3.80	4.65	2.45	F	FD	
	1 018	275.00	275.00	1519	18.9	85	3.50	2.30	4.60	3.80	3.90	3.05	F	FD	
	1 018	276.00	276.00	1519	18.9	85	0.00	4.20	4.60	4.30	3.90	2.60	F	FD	
	1 018	277.00	277.00	1519	18.9	85	3.50	2.30	3.10	5.00	4.65	2.90	F	FD	
	1 018	277.91	277.91	1592	14.2	77	4.80	5.00	5.00	5.00	4.65	4.10	A	FD	
	1 018	278.00	278.00	1624	12.1	73	4.40	5.00	5.00	5.00	4.30	3.85	A	FD	
	1 018	282.00	282.00	1365	16.5	77	3.50	4.20	5.00	5.00	5.00	4.30	A	FD	
3	1 018	348.00	348.00	786	18.8	44	4.80	6.00	6.00	6.00	4.30	4.67	O	FD	
	1 037	044.00	044.00	1785	12.0	80	0.00	3.90	3.40	4.30	5.00	4.35	A	FD	
	1 037	045.00	045.00	1785	12.0	80	4.50	3.50	3.10	3.00	5.00	3.95	A	FD	
	1 037	037 045.00+00.500	045.00	1785	12.0	80	5.00	5.00	5.00	5.00	5.00	4.30	A	FD	
	1 037	046.00	046.00	1785	12.0	80	4.50	3.50	2.70	4.30	4.30	3.60	A	FD	
	1 037	047.00	047.00	1785	12.0	80	4.80	3.90	2.20	5.00	5.00	4.20	A	FD	
	1 037	048.00	048.00	1785	12.0	80	3.50	3.10	3.50	4.30	4.65	3.65	A	FD	
	1 037	049.00	049.00	1785	12.0	80	3.50	3.50	2.70	4.30	4.65	3.70	A	FD	
	1 037	050.00	050.00	1785	12.0	80	3.50	4.60	2.70	5.00	5.00	3.95	A	FD	
	1 037	037 050.52+00.026	050.52	1785	12.0	80	5.00	5.00	5.00	5.00	4.65	3.95	A	FD	
	1 037	051.00	051.00	1785	12.0	80	4.50	2.70	0.80	5.00	4.65	3.75	A	FD	
	1 037	037 063.00+00.583	063.00	2364	16.4	133	4.50	4.60	5.00	5.00	5.00	4.20	F	FD	
	1 037	064.00	064.00	2364	16.4	133	4.50	4.60	4.20	5.00	5.00	4.40	F	FD	
	1 037	066.00	066.00	2364	16.4	133	4.50	3.10	4.20	5.00	4.65	4.50	F	FD	
	1 037	037 066.50+00.002	066.50	2364	16.4	133	4.50	4.60	4.20	5.00	4.65	4.65	F	FD	
	1 037	067.00	067.00	2364	16.4	133	4.50	3.10	4.20	4.30	5.00	4.65	F	FD	
	1 037	068.00	068.00	2364	16.4	133	3.50	4.20	5.00	5.00	5.00	4.65	F	FD	
	1 037	070.00	070.00	2364	16.4	133	3.50	2.30	4.20	5.00	5.00	4.65	F	FD	
	1 044	253.58	253.58	4660	8.6	169	4.50	4.60	4.60	5.00	1.75	4.30	A	FD	
	1 044	254.00	254.00	1665	11.7	67	0.00	3.80	4.20	5.00	4.65	3.50	A	FD	
	1 044	255.00	255.00	1170	13.2	52	0.00	2.50	4.20	5.00	3.90	1.60	A	FD	
	1 044	256.00	256.00	1170	13.2	52	0.00	3.40	5.00	5.00	3.90	3.55	A	FD	
	1 044	257.00	257.00	1170	13.2	52	0.00	3.40	1.90	5.00	3.90	3.35	A	FD	
	1 044	258.00	258.00	1170	13.2	52	0.00	2.90	1.90	5.00	3.90	2.00	A	FD	
	1 044	044 258.00+00.500	258.00	1170	13.2	52	0.00	3.40	1.90	5.00	3.50	1.60	A	FD	
	1 044	259.00	259.00	1170	13.2	52	0.00	2.50	4.20	5.00	3.90	3.35	A	FD	
	1 044	260.00	260.00	1170	13.2	52	0.00	3.40	1.90	5.00	4.30	4.15	A	FD	
	1 044	261.00	261.00	1170	13.2	52	0.00	3.40	1.90	5.00	3.90	3.20	A	FD	
	1 044	261.53	261.53	464	11.7	21	2.80	4.60	4.20	5.00	4.30	3.55	A	FD	
	1 044	262.00	262.00	425	11.6	19	2.80	4.60	4.20	5.00	4.30	4.20	A	FD	
	1 044	263.00	263.00	425	11.6	19	4.00	4.60	5.00	5.00	5.00	4.35	A	FD	
4	1 080 W	213.00	213.00	2870	24.7	288	6.41	7.01	7.24	7.24	7.24	3.88	F	FD	
5	1 212	NON-DESCRIPT	367.00	3369	11.6	180	4.90	6.00	6.00	6.00	6.00	6.00	F	FD	

	FROM_ROAD	BEGIN_MRM	95TRAN-CK	95FATG-CK	95PTCHDT	95BLK-CK	95RUT-DP	95ROUGH	95PAVFLG	95PAVTYP	96TRAN-CK	96FATG-CK	96PTCHDT	96BLK-CK	96RUT-DP	96ROUGH	96PAVFLG	96PAVTYP	YEAR_INTL	YR_LST_IMP	SINCE_IMPR	COUNTY_NO	HIGH_REG	AREA_CODE	FUNC_CLASS	ELEM_ID
1	1 012	NON-DESCRIPT	3.80	2.80	6.00	3.80	6.00	4.80	A	THK	3.80	2.80	6.00	3.80	6.00	4.80	A	TKLD	1987	1988	9	Day	Aberdeen Region	M88880	Rur. Prncpl. Artl. Other	0003000000000
	1 012	012 319.00+00.266	4.80	5.00	5.00	5.00	5.00	4.87	A	FD	4.70	5.00	5.00	5.00	5.00	4.87	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000000
	1 012	320.00	4.60	5.00	5.00	5.00	5.00	4.85	A	FD	4.60	5.00	5.00	5.00	5.00	4.85	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000000
	1 012	321.00	4.30	5.00	5.00	5.00	5.00	4.67	A	FD	4.80	5.00	5.00	5.00	5.00	4.67	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000000
	1 012	322.00	4.50	5.00	5.00	5.00	5.00	4.56	A	FD	4.80	5.00	5.00	5.00	5.00	4.56	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000000
	1 012	323.00	4.50	5.00	5.00	5.00	5.00	4.65	A	FD	4.30	5.00	5.00	5.00	5.00	4.65	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000000
	1 012	324.00	4.60	5.00	5.00	5.00	5.00	4.75	A	FD	4.60	5.00	5.00	5.00	5.00	4.75	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000000
	1 012	327.00	4.30	5.00	5.00	5.00	5.00	4.70	A	FD	4.80	5.00	5.00	5.00	5.00	4.70	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000000
	1 012	328.00	4.80	5.00	5.00	5.00	5.00	4.58	A	FD	4.80	5.00	5.00	5.00	5.00	4.58	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000000
	1 012	329.00	4.50	5.00	5.00	5.00	4.65	4.67	A	FD	4.70	5.00	5.00	5.00	4.65	4.67	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000001
	1 012	330.00	4.30	5.00	4.60	5.00	4.65	4.52	A	FD	4.70	5.00	4.80	5.00	4.65	4.52	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000001
	1 012	331.00	4.60	5.00	5.00	5.00	5.00	4.80	A	FD	4.70	5.00	5.00	5.00	5.00	4.80	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000001
	1 012	332.00	4.30	5.00	5.00	5.00	5.00	4.73	A	FD	4.70	5.00	5.00	5.00	5.00	4.73	A	FD	1971	1990	7	Day	Aberdeen Region	Aberdeen Area	Rur Prncpl Artl Other	0003000000001
	1 014 EL	011.00	4.80	5.00	5.00	5.00	4.65	4.60	F	FD	4.30	5.00	5.00	5.00	4.85	4.80	F	FD	1971	1990	7	Lawrence	Rapid City Region	Rapid City Area	Urb Prncpl Artl Other	000C000000000
	1 014 WL	011.00	4.40	5.00	5.00	5.00	4.30	4.50	F	FD	3.80	5.00	5.00	5.00	4.30	4.50	F	FD	1971	1990	7	Lawrence	Rapid City Region	Rapid City Area	Urb Prncpl Artl Other	000F000000000
	1 015	015 149.00+00.861	4.50	5.00	5.00	5.00	4.65	4.55	A	FD	4.50	5.00	5.00	5.00	4.85	4.55	A	FD	1971	1990	7	Deuel	Aberdeen Region	Brookings Area	Rural Minor Arterial	000H000000000
	1 015	150.00	4.50	5.00	5.00	5.00	5.00	4.70	A	FD	4.80	5.00	5.00	5.00	5.00	4.70	A	FD	1971	1990	7	Deuel	Aberdeen Region	Brookings Area	Rural Minor Arterial	000H000000000
2	1 016A	NON-DESCRIPT	4.80	6.00	6.00	6.00	6.00	4.80	F	FD	3.70	4.80	6.00	6.00	6.00	4.80	F	FD	1978	1982	8	Pennington	Rapid City Region	Custer Area	Rural Minor Arterial	0000000000000
	1 018	254.00	4.90	4.80	5.00	5.00	4.30	4.58	A	FD	4.90	4.80	5.00	5.00	4.30	4.56	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	255.00	4.80	4.80	5.00	5.00	3.90	4.75	A	FD	4.80	4.20	5.00	5.00	3.90	4.75	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	256.00	4.60	4.80	5.00	5.00	3.90	4.52	A	FD	4.50	4.80	5.00	5.00	3.90	4.52	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	257.00	4.80	4.80	5.00	5.00	3.90	4.50	A	FD	4.50	4.60	5.00	5.00	3.90	4.50	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	258.00	4.60	4.80	5.00	5.00	3.90	4.65	A	FD	4.50	4.20	5.00	5.00	3.90	4.65	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	259.00	4.50	4.80	5.00	5.00	3.90	4.56	A	FD	4.80	4.20	5.00	5.00	3.90	4.58	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	260.00	4.50	4.80	5.00	5.00	3.90	4.80	A	FD	4.30	4.60	5.00	5.00	3.90	4.80	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	018 260.00+00.500	4.50	4.80	5.00	5.00	3.90	4.60	A	FD	4.50	4.80	5.00	5.00	3.90	4.80	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	261.00	4.80	4.80	5.00	5.00	3.90	4.15	A	FD	4.80	4.80	5.00	5.00	3.90	4.15	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	263.00	4.60	5.00	5.00	5.00	4.30	4.82	A	FD	4.80	4.60	5.00	5.00	4.30	4.82	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	263.33	4.90	5.00	5.00	5.00	5.00	4.60	A	FD	4.90	4.60	5.00	5.00	6.00	4.60	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	018 263.34+00.226	4.80	5.00	5.00	5.00	4.65	4.40	A	FD	4.90	5.00	5.00	5.00	4.65	4.40	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur Prncpl Artl Other	000S000000000
	1 018	274.00	3.40	4.20	5.00	3.80	4.30	3.85	F	FD	3.70	3.80	4.60	3.80	4.30	3.85	F	FD	1974	1988	9	Gregory	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	000S000000000
	1 018	018 274.00+00.250	4.40	4.20	5.00	3.80	4.30	3.90	F	FD	4.30	3.40	4.60	3.80	4.30	3.90	F	FD	1974	1988	9	Gregory	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	000S000000000
	1 018	275.00	3.40	4.20	5.00	3.80	3.90	3.80	F	FD	3.40	2.80	5.00	3.80	3.90	3.80	F	FD	1974	1988	9	Gregory	Mitchell Region	Mitchell Area	Rur Prncpl. Artl Other	000S000000000
	1 018	276.00	3.40	3.80	5.00	4.30	3.90	3.95	F	FD	3.40	3.80	5.00	4.30	3.90	3.95	F	FD	1974	1988	9	Gregory	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	000S000000000
	1 018	277.00	4.40	4.60	5.00	5.00	4.30	4.50	F	FD	4.30	2.80	5.00	5.00	4.30	4.50	F	FD	1974	1988	9	Gregory	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	000S000000000
	1 018	277.91	4.90	5.00	5.00	5.00	4.65	3.70	A	FD	4.90	5.00	5.00	5.00	4.65	3.70	A	FD	1974	1988	9	Gregory	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	000S000000000
	1 018	278.00	4.90	5.00	5.00	5.00	5.00	4.50	A	FD	4.70	5.00	5.00	5.00	5.00	4.50	A	FD	1974	1988	9	Gregory	Mitchell Region	Mitchell Area	Rur Prncpl Artl. Other	000S000000000
	1 018	282.00	4.50	4.80	5.00	5.00	4.30	4.55	A	FD	4.60	4.20	5.00	5.00	4.30	4.55	A	FD	1973	1990	7	Tripp	Pierre Region	Winner Area	Rur. Prncpl Artl. Other	000S000000000
3	1 018	348.00	4.80	6.00	6.00	6.00	4.65	4.80	O	FD	4.80	6.00	6.00	6.00	4.65	4.80	O	THK	1944	1980	4	Charle Mix	Mitchell Region	Yankton Area	Rural Minor Arterial	0008000000000
	1 037	044.00	4.50	5.00	4.60	3.00	5.00	4.50	A	FD	4.30	5.00	4.60	3.00	5.00	4.50	A	FD	1949	1978	19	Hutchinson	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	045.00	4.60	5.00	4.60	3.00	5.00	4.20	A	FD	4.50	5.00	4.60	3.00	5.00	4.20	A	FD	1949	1978	19	Hutchinson	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	037 045.00+00.500	4.50	5.00	4.60	3.00	5.00	3.95	A	FD	3.30	3.10	4.60	3.00	5.00	3.95	A	FD	1949	1978	19	Hutchinson	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	046.00	4.50	5.00	4.60	3.00	4.30	2.90	A	FD	4.60	3.90	2.70	3.00	4.30	2.90	A	FD	1949	1978	19	Hutchinson	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	047.00	4.50	5.00	5.00	3.00	4.65	3.95	A	FD	3.30	3.90	3.80	3.00	4.65	3.95	A	FD	1949	1978	19	Hutchinson	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	048.00	4.50	4.20	5.00	3.00	4.30	3.60	A	FD	4.30	3.10	3.50	3.00	4.30	3.80	A	FD	1949	1978	19	Hutchinson	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	049.00	4.50	3.90	5.00	5.00	4.65	3.90	A	FD	3.90	3.90	2.70	3.00	4.65	3.90	A	FD	1949	1978	19	Hutchinson	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	050.00	4.50	5.00	4.60	5.00	4.65	3.95	A	FD	3.20	4.60	3.80	5.00	4.65	3.95	A	FD	1949	1978	19	Hutchinson	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	037 050.52+00.026	2.30	5.00	3.80	3.00	4.30	3.70	A	FD	2.10	3.50	3.80	1.40	4.30	3.70	A	FD	1949	1978	19	Hutchinson	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	051.00	4.80	5.00	4.20	5.00	4.65	4.05	A	FD	4.20	5.00	5.00	3.00	4.65	4.05	A	FD	1949	1978	19	Hutchinson	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	037 063.00+00.583	4.50	4.60	5.00	5.00	5.00	4.50	F	FD	4.50	4.60	5.00	5.00	5.00	4.50	F	FD	1946	1991	6	Davison	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	064.00	4.50	4.60	5.00	5.00	5.00	4.70	F	FD	4.60	4.60	5.00	5.00	5.00	4.70	F	FD	1946	1991	6	Davison	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	066.00	4.60	4.20	5.00	5.00	4.65	4.52	F	FD	4.50	3.10	5.00	5.00	4.65	4.52	F	FD	1946	1991	6	Davison	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	037 066.50+00.002	4.50	4.60	5.00	5.00	4.30	4.67	F	FD	4.60	4.80	5.00	5.00	4.30	4.87	F	FD	1946	1991	6	Davison	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	067.00	4.50	4.60	5.00	5.00	4.30	4.73	F	FD	4.50	4.20	5.00	5.00	4.30	4.73	F	FD	1946	1991	6	Davison	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	068.00	4.50	4.20	5.00	5.00	4.65	4.70	F	FD	4.50	4.20	5.00	5.00	4.65	4.70	F	FD	1946	1991	6	Davison	Mitchell Region	Mitchell Area	Rur Prncpl Artl Other	001G000000000
	1 037	070.00	4.50	3.40	5.00	5.00	4.65	4.70	F	FD	4.50	2.30	5.00	5.00	4.65	4.70	F	FD	1946	1991	6	Davison	Mitchell Region	Mitchell Area	Rur Prncpl Artl. Other	001G000000000
	1 044	253.58	4.80	4.60	5.00	5.00	3.50	2.15	A	FD	4.70	4.60	4.60	5.00	3.50	2.15	A	FD	1959	1984	13	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	254.00	4.40	4.20	4.20	5.00	3.50	4.25	A	FD	3.80	3.80	4.20	6.00	3.50	4.25	A	FD	1959	1984	13	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	255.00	4.40	3.80	4.20	5.00	3.90	3.05	A	FD	4.30	3.40	4.20	5.00	3.90	3.05	A	FD	1959	1984	13	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	256.00	4.40	4.60	4.20	5.00	3.90	4.25	A	FD	3.90	2.80	5.00	5.00	3.90	4.25	A	FD	1959	1984	13	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	257.00	4.30	3.80	4.20	5.00	4.30	4.35	A	FD	3.70	4.20	5.00	6.00	4.30	4.35	A	FD	1959	1984	13	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	258.00	4.40	4.60	3.30	5.00	3.90	4.30	A	FD	2.60	4.20	5.00	5.00	3.90	4.30	A	FD	1959	1984	13	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	044 258.00+00.500	4.40	4.60	3.30	5.00	3.90	4.25	A	FD	3.70	3.80	3.30	5.00	3.90	4.25	A	FD	1959	1984	13	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	259.00	4.40	3.80	4.20	5.00	4.30	4.50	A	FD	3.80	3.80	5.00	5.00	4.30	4.50	A	FD	1959	1984	13	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	260.00	4.40	4.60	3.30	5.00	3.90	4.82	A	FD	3.70	4.20	3.30	5.00	3.90	4.82	A	FD	1959	1984	13	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	261.00	4.60	5.00	5.00	5.00	3.50	4.15	A	FD	3.80	4.20	5.00	5.00	3.50	4.15	A	FD	1959	1984	13	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	261.53	4.30	5.00	4.20	5.00	4.30	3.50	A	FD	3.70	4.60	5.00	5.00	4.30	3.50	A	FD	1971	1986	11	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	262.00	4.80	4.60	4.20	5.00	4.65	4.35	A	FD	4.70	4.60	4.20	5.00	4.65	4.35	A	FD	1971	1986	11	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
	1 044	263.00	4.80	5.00	4.20	5.00	5.00	4.65	A	FD	4.70	5.00	5.00	5.00	5.00	4.65	A	FD	1971	1986	11	Tripp	Pierre Region	Winner Area	Rural Minor Arterial	001Q000000000
4	1 080 W	213.00	7.12	7.24	7.24	7.24	7.04	3.84	F	FD	6.30	7.01	7.24	7.24	7.04	3.84	F	FD	1971	1980	7	Lyman	Pierre Region	Winner Area	Rur. Prncpl. Artl. Inter	002C000000000
5	1 212	NON-DESCRIPT	0.00	0.00	0.00	0.00	0.00	0.00	A	?????	9.99	9.99	9.99	9.99	9.99	9.99	A	?????	1980	1987	0	Codington	Aberdeen Region	Brookings Area	Rur. Prncpl. Artl. Other	003E000000000

ASPHALT ON CONCRETE PAVEMENT FAMILY: SAMPLE ERRORS

	FROM_ROAD	BEGIN_MRM	BEG_MILEAG	CUR_ADT	PCT_TRUCK	ESALS_FLEX	97TRAN-CK	97FATG-CK	97PTCHDT	97BLK-CK	97RUT-DP	97ROUGH	97PAVFLG	97PAVTYP	97COMMENT
6	1 106	006.00	006.00	1286	4.5	20	4.80	2.30	4.80	6.00	6.00	4.70	A	AONC	
7	1 116	081.18	081.18	16914	3.9	234	9.99	9.99	9.99	9.99	9.99	3.70	O	AONC	

	FROM_ROAD	BEGIN_MRM	95TRAN-CK	95FATG-CK	95PTCHDT	95BLK-CK	95RUT-DP	95ROUGH	95PAVFLG	95PAVTYP	96TRAN-CK	96FATG-CK	96PTCHDT	96BLK-CK	96RUT-DP	96ROUGH	96PAVFLG	96PAVTYP	YEAR_INTL	YR_LST_IMP	SINCE_IMPR	COUNTY_NO	HIGH_REG	AREA_CODE	FUNC_CLASS	ELEM_ID
6	1 106	006.00	4.80	6.00	6.00	6.00	6.00	4.70	A	AONC	3.80	3.40	6.00	6.00	6.00	4.70	A	AONC	2028	1989	8	Union	Mitchell Region	Yankton Area	Urban Minor Arterial	002U000000000
7	1 116	081.18	9.99	9.99	9.99	9.99	9.99	4.80	O	AONC	9.99	9.99	9.99	9.99	9.99	6.00	O	TKLD	2029	1979	18	Minnehaha	Mitchell Region	Sioux Falls Area	Urban Minor Arterial	002X000000000

THICK SHORT JOINTED CONCRETE PAVEMENT FAMILY: SAMPLE ERRORS

	HIGHWAY	BEGIN_MRM	END_MRM	CUR_ADT	PCT_TRUCK	ESALS_RIGD	97ROUGH	97DASR	97JNT-SPL	97CRNR-CK	97FAULT	97JNT-SLD	97PUNCH	97PAVFLG	97PAVTYP	97COMMENT
8	1 014A	042.00	NON-DESCRIPT	3980	6.1	206	4.00	6.00	4.60	4.96	0.36	4.65	6.00	J	TKBJ	
9	1 044	046.13	NON-DESCRIPT	28300	4.3	880	4.80	1.80	2.30	6.00	1.90	4.20	6.00	J	TKBJ	

	HIGHWAY	BEGIN_MRM	95ROUGH	95DASR	95JNT-SPL	95CRNR-CK	95FAULT	95JNT-SLD	95PUNCH	95PAVFLG	95PAVTYP	96ROUGH	96DASR	96JNT-SPL	96CRNR-CK	96FAULT	96JNT-SLD	96PUNCH	96PAVFLG	96PAVTYP	YEAR_INTL	YR_LST_IMP	SINCE_IMPR	HIGH_REG	COUNTY_NO	AREA_CODE	FUNC_CLASS	ELEM_ID
8	1 014A	042.00	4.80	6.00	4.07	6.00	0.36	6.00	6.00	J	TKBJ	4.72	6.00	4.60	4.96	4.41	6.00	6.00	J	TKBJ	1986	1988	11	Rapid City Region	Lawrence	Rapid City Area	Rur. Prncpl. Artl. Other	0000000000000
9	1 044	046.13	4.80	6.00	0.20	6.00	1.80	3.00	6.00	J	TKBJ	4.80	0.80	0.00	6.00	1.80	0.00	6.00	J	TKBJ	1988	1988	38	Rapid City Region	Pennington	Rapid City Area	Urban Minor Arterial	0010000000000

Figure D.1 Sample Data Files for Flexible Pavements (Full Depth and Asphalt on Concrete) and Rigid Pavements (Thick Short Jointed Concrete) and Data File Errors.

D.3.1 Errors Due To Improper Field Data

These are the obvious errors in the database that are very easy to identify and correct or eliminate. Pavement sections containing improper field data cannot be used for the development of the performance models due to any of the following reasons:

1. These sections have distress condition scores that are either less than 0.00 (minimum allowable score) or are greater than 5.00 (maximum allowable score).
   In figure D.1 pavement sections flagged as number 4 and 5 have distress condition scores greater than 5.00 and hence they have to be removed from the database.

2. These sections are lacking in critical information such as pavement condition, pavement flag, or pavement type. These sections usually contain data cells that are either blank or have a series of interrogation marks (?????) instead of the actual data. Since it is impossible to correctly identify the appropriate pavement family and associated condition, these sections cannot be used for developing performance curves.

   In figure D.1 pavement section flagged as number 5 contains "?????" for the 1995 and 1996 pavement type and hence this section has to be removed from the database.

3. These sections contain default values for individual condition scores, identified by specific comments, and hence they cannot be used for developing performance curves for that particular distress index. Such comments, if any, usually exist in the "COMMENT" column in the database.

   In figure D.1 pavement section flagged as number 2 contains an entry in the 97COMMENT column that says "BLACK HILLS DEFAULT ROUGHNESS." Hence the roughness data of this particular section cannot be used for developing the roughness performance curve for this particular pavement family.

4. Often there are pavement sections that have absurd data entries such as year value of 2028/29 for last improvement made on that pavement section or an initial construction date that is higher than the year since last improvement. (e.g. pavement sections, from the AONC family, flagged as number 6 and 7). Again these sections have to be removed from the database before the database can be used for the statistical analyses.

Improper field data errors of the types identified above are fairly common in pavement condition databases. Once converted into a spreadsheet format (MS Excel) it is easiest to identify these errors using in-built functions such as Sort and Filter. The Filter function in particular allows the user to define the allowable data variations and then isolate the data entries that do not conform to the requirements. Similarly the Sort function can also be used to isolate data entries that have unacceptably small or large values except that the Sort function does not allow the user to customize the allowable data variations.

These errors, as mentioned earlier are very obvious and hence very easy to identify once the user is familiar with the structure of the database, the scope of the data entries, and their relevance and variations that are to be allowed for the individual data entries.

D.3.2 Errors Due To Improper Pavement Family Transition

These errors are the ones that arise when the data entries do not conform to the expected transition in the pavement families following particular rehabilitation treatments or otherwise. These errors are difficult to detect since they do not exist as obviously incorrect or absurd data entries. These errors occur in pavement sections under any of the following circumstances:

1. Sections that show a change in the pavement type (family) from one year to another without identifying the appropriate year since last improvement. In most cases it is not possible to figure out whether the section has incorrect pavement type information or incorrect year since last improvement and so pending further information such sections have to be removed from the database.

   In figure D.1 pavement section flagged as number 3 shows such a pavement section. This particular section has a pavement type of FD-O (Original Full Depth Asphalt) in year 1995, then a pavement type of THK-O (Original Thick Asphalt) in year 1996 and then again a pavement type of FD-O (Original Full Depth Asphalt) in year 1997. Considering that the year since last improvement has been registered as 1993 it is obvious that the section data is erroneous. Hence this section has to be removed from the database.

2. To cite a particular case of improper family transition some of the concrete families have a "J" pavement flag indicating the implementation of minor joint and spall repair (<40% of the joints) since original construction. But these pavement sections have the same initial year and year since last improvement indicating that there has been no substantial improvement done on these sections since their construction.

   In figure D.1 pavement sections flagged as number 8 and 9 are examples of such errors. In this case we were able to check the validity of the data entries and find out that the 'J" flags should be substituted by an "O" flag indicating that these are original pavement sections. In absence of such additional information these sections should be removed from the database.

It has been found that the errors due to improper pavement family transition are somewhat difficult to detect and require a careful, record-by-record inspection of the database. This can be done either by checking the printout for each individual database (spreadsheet/*.xls) or by checking the database on the computer screen. A useful tip for identifying these sections is to hide all data columns (inventory, traffic and condition) that do not contribute to these errors.

D.3.3 Developing Pavement Families and Preparing Data Sets

The Data Censorship procedure helps the user to create databases (spreadsheet/*.xls) – for individual pavement families – which are free of all types of errors and file corruption. These files are then ready to be used for carrying out statistical analysis towards using the historical data for developing pavement performance curves.

At this stage the data files can either be combined or separated depending upon the scope of the statistical analysis. For example, to further split the Thick Asphalt family (say, THK.XLS) into separate pavement families for Thick Asphalt Original (O), AC Overlay (A), and Mill and AC Overlay (F), the user is required to separate the records based on the pavement flag (O, A, or M) and create separate files (say THK-O.XLS, THK-A.XLS, and THK-M.XLS, respectively), each of which can then be analyzed by itself. Similarly, records from two or more files can be combined into one file to merge different pavement families into a single family. Since the S-Plus program has been developed to handle MS Excel files it is recommended that all data files be converted into that format before executing the regression modeling procedure.

As discussed earlier, figure D.1 shows the structure of a typical pavement condition data file. The data file contains rows of records for individual pavement sections. The column headings identify the type of information contained in each record. Recommended guidelines for preparing the data sets/files before conducting the statistical analysis are:

1. The data file must be saved as a MS Excel (*.xls) file and copied into the appropriate folder.

2. The first row of the data file should always contain the column headings. It is not required to leave any rows empty either after the heading row or between records. Even though it is not important to maintain the sequence of the columns in the data file a fixed sequence of columns in every data file will simplify and reduce the user inputs during the data familiarization process. Figure D.1 shows sample data file format for both a flexible pavement family (FD.XLS & AONC.XLS) and a rigid pavement family (TKSJ.XLS).

3. The Pavement Performance Modeling Tool (PPMT) used by S-Plus for conducting the regression analysis is customized to recognize condition index variables as column headings beginning with the two-digit year signifying the year of the condition survey. Hence all distress condition index columns should have a column heading beginning with a two-digit year and then the code for the particular index. E.g. 97TRAN-CK, 95ROUGH, 96JNT-SLD and so on. Interestingly, this feature also allows the user to carry out regression analysis on any variable by adding a two-digit year code as a prefix to its column heading.

4. The PPMT calculates the age of different sections based on the columns YEAR_INITL, YR_LST_IMP, and SINCE_IMPR. Hence it is strongly recommended that the format of these column headings be always kept the same.

Preparation of the data sets in terms of MS Excel data files completes the data preparation phase. The user should now have the appropriate input files required for carrying out regression analysis, based on the historical data, for developing pavement performance curves.

D.4 Statistical Analyses

The statistical analyses required for developing the pavement performance curves is performed by using a statistical applications software – S-Plus 4.5 Standard Edition (MathSoft, Inc.) for Windows. This software allows the user to incorporate "macros" or program "scripts" that can automatically retrieve data in the spreadsheet format, carry out regression modeling procedures based on user-defined parameters, and generate performance curves based on the selected data. The actual program "scripts" have been developed using the Professional Edition of S-Plus 4.0

Release 3.0 This software is particularly useful because it allows the developer to customize the output parameters while allowing the user to compare different regression models at the same time. The program "scripts" created for developing pavement performance curves will henceforth be referred to as PPMT scripts.

D.4.1 Basic Outlines For Setting up the S-Plus Program Script

When the S-Plus 4.5 program is installed on a computer it creates a folder named "\splus45\users\administrator" in the root directory where the S-Plus 4.5 Standard program has been installed. The default folder "administrator" can be given a different name during the installation process (figure D.2 shows the folder being customized to be c:\splus45\users\models, during the installation process). For pavement performance modeling, the PPMT scripts customized to carry out the regression modeling are to be copied into this folder. The five script files are getdata.ssc, gqmeth.ssc, load.ssc, rrqmeth.ssc, and run.ssc.

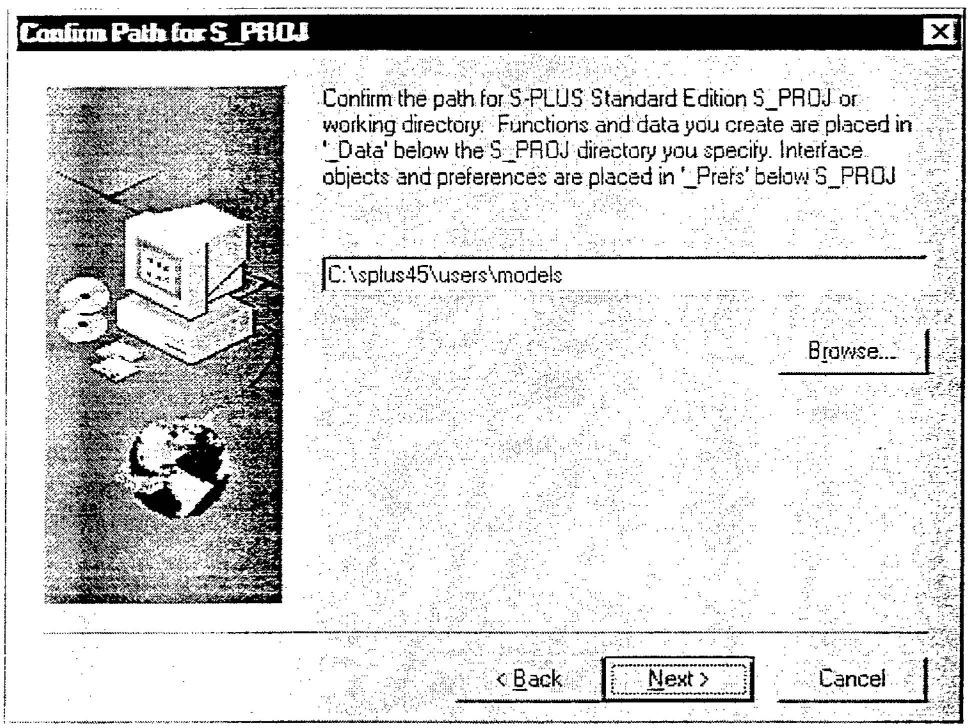


Figure D.2 Selecting a name for the working directory during installation of S-Plus 4.5.

To run the pavement modeling "script" program for the first time the PPMT scripts must be loaded onto S-Plus in "BATCH" mode. This is accomplished through the following steps:

1. Click the Windows "Start" button and select the 'Run" option. In the open field that appears type in the following command:

   "C:\splus45\cmd\Splus.exe" /BATCH "C:\splus45\users\models\load.ssc" load.out

2. Once the pavement modeling "scripts" have been loaded an additional pull-down menu named "Pavement" will appear on the S-Plus toolbar. This menu will provide the user with all the required command options.

3. Start the S-Plus program. Once the PPMT scripts are loaded in the "BATCH" mode they will be in operation every time the S-Plus program is started.

To successfully load the PPMT program it is important that the PPMT script files be installed into the appropriate folder (\splus45\users\models (working directory)).

D.4.2 Stepwise Procedure for Regression Modeling

Now we shall discuss the step-by-step procedure to be followed for generating performance curves for each distress index of individual pavement families. To facilitate the easy retrieval of data by the S-Plus program it is strongly recommended that the spreadsheet data files also be copied into the \splus45\users\models (working dirtectory) folder. Locating the data files during the regression modeling procedure will be much simpler if the data files are placed in the recommended folder.

1. The first step in the regression modeling procedure is to recall the data file for the pavement family for which the performance models are to be developed. Click the **Pavement** menu option and select the "**GetData...**" option from the pull-down menu. The program then pops up a window asking the user to identify the name of the data file (*.xls) (e.g. THK-A.XLS.), based on which the performance models are to be developed. (See figure D.3)

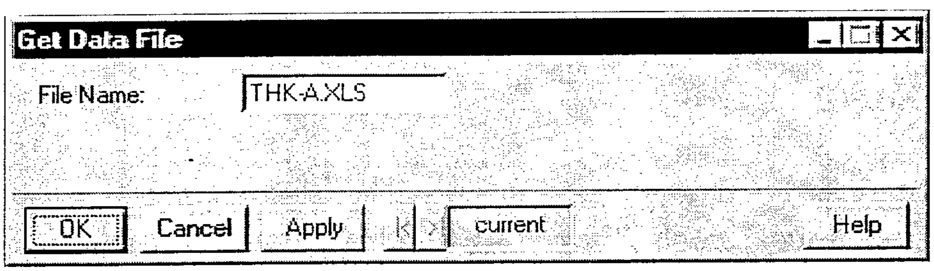


Figure D.3 PPMT interface allowing user to select the data file (*.xls) of interest.

After identifying the files, click OK and wait for S-Plus to retrieve the selected data file. If the data files are not placed in the recommended folder (\splus45\users\models (working directory)) then the user will need to identify the entire path for the location of the data file. Since the file is placed in the appropriate folder it is sufficient to just identify the data file by its name (e.g. THK-A.XLS). Once the data file has been retrieved by S-Plus it will be displayed in a spreadsheet format as a window – holddata – which can be used for confirming the selection of the appropriate data file (See figure D.4). While running the PPMT program the holddata window can be minimized or even closed. S-Plus allows the user to access this window by double-clicking the holddata folder from the Object Browser window.

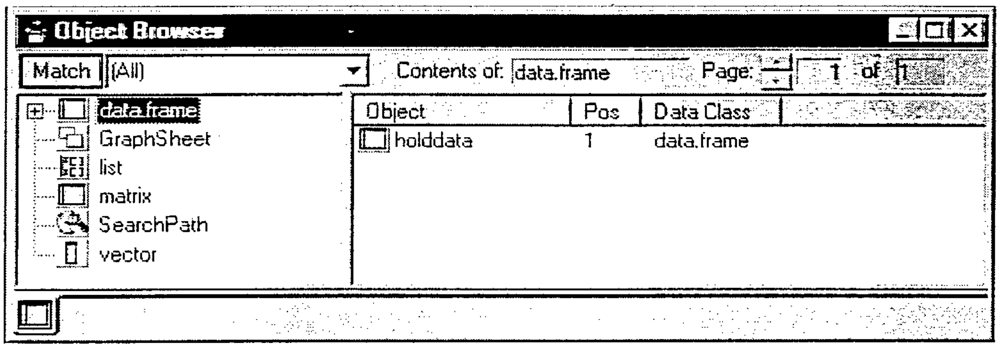


Figure D.4 Object Browser window that allows user access to current data file (holddata).

2. Once the required data file has been retrieved again click the **Pavement** menu option and select the "**Model...**" option from the pull-down menu. S-Plus will pop-up another PPMT interface that will allow the user to input the parameters for carrying out the regression analysis. (See figure D.5).

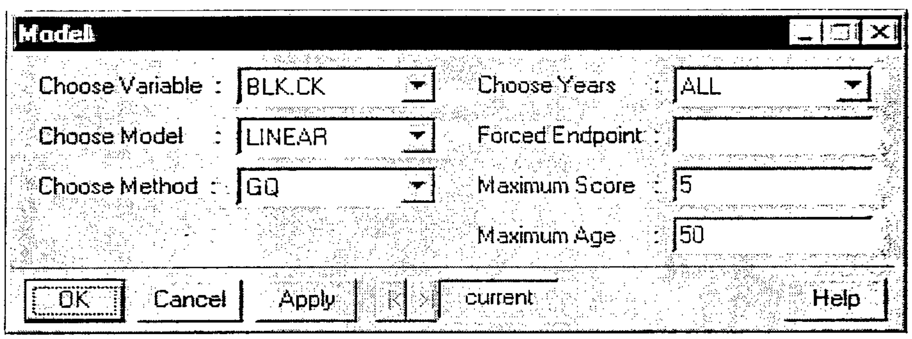


Figure D.5 PPMT interface allowing user to select parameters for regression modeling.

Here the user is asked to select various parameters that govern the regression modeling:

- From the pull-down menu for "Choose Variable," select the particular distress condition index for which the performance model is to be generated.
- From the "Choose Model" pull-down menu, select one of the four model forms (Linear, Power, Cubic, and Quadratic) that can be used for developing performance curves.
- The "Choose Method" pull-down menu allows the user to select either the GQ (default) method or the RQ method. The GQ method is recommended for use while conducting regression analysis for pavement performance modeling. Discussion regarding the two methods is included in the final report.
- The "Choose Years" pull-down menu allows the user to select either the particular year of interest (here 1995, 1996, and 1997) or for all the years combined (ALL). Performance curves can be generated either based on data from a single year or for all the years combined.

- The "Forced Endpoint" box allows the user to enter a forced endpoint for the performance curve, if required. The details of the forced endpoint procedure are discussed in the section D.4.4.
- The "Maximum Score" box allows the user to specify the upper boundary limit for the condition index. Since the condition indexes currently being used for the South Dakota Department of Transportation (SDDOT) are on a scale of 0.00 to 5.00 the default value for maximum score is defined as 5.00. However this feature will allow the user to incorporate a new maximum score (say, 100) if the indexes are modified in future.
- The "Maximum Age" box allows the user to set the upper limit up to which the output chart will be displayed. Accepting the default value of 50 will generate a chart with the x-axis variable (age) extending up to 50 years.

3. After selecting the parameters for the regression analysis click "OK" (or "Apply") for the PPMT to actually generate the selected performance curve; click "Cancel" to cancel the selected model. Every new model being generated will show up as "current" at the bottom of the Model interface. The scroll bar adjoining it can be used to recall parameters of previously generated performance models. Currently the "Help" functionality is not available through the PPMT interface.

4. Once the "OK" button has been clicked from the Model window, PPMT will generate the charts based on the selected parameters. Each Model function creates two graph sheets – one with non-jittered data points and another with jittered data points. (Refer to section D.4.3).

D.4.3 Sample Graphs and Interpretation of Performance Curves

The graph sheets generated by the PPMT program display the actual regression plot for the selected condition index vs. age along with the output parameters. Figures D.6 through D.10 show the sample graph sheets as displayed by the PPMT program. These performance curves are for the "Thick Asphalt pavement with an AC Overlay" (THK-A.XLS) family plotted for Block Cracking Index (BLK.CK) versus pavement age. Sample graph sheets include all four model forms: Linear (figure D.6), Power (figure D.7), Cubic (figure D.8), and Quadratic (figure D.10). Descriptions of the features of these example graphs are given below.

- The y-axis indicates the score of the selected distress condition index (0 to 5) and the x-axis indicates the age of the pavement in years (0 year to 50 years). The "n" value below the x-axis indicates the number of data points in the graph.

- As discussed earlier in the report, each graph sheet plots three curves: 25th quantile curve, 50th quantile curve, and the 75th quantile curve. For obtaining an equation to be used as a pavement performance model, the 50th quantile curve is recommended since it represents the median state of pavement condition.

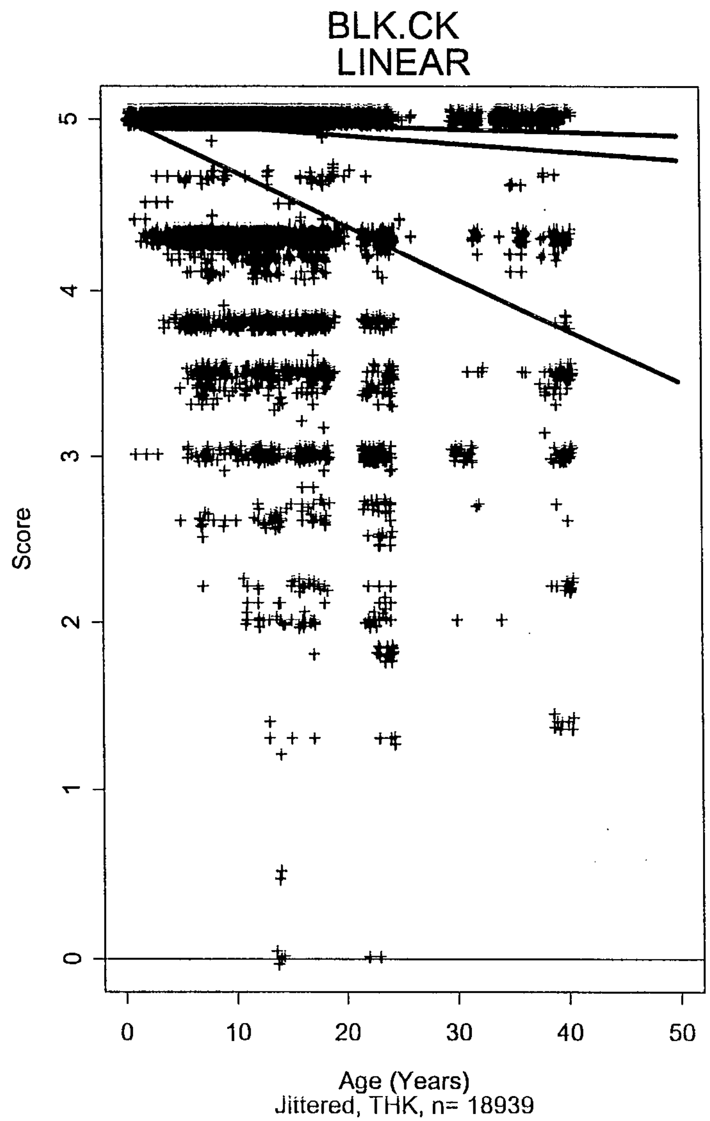
- The output parameters also include the R-squared value, the Standard Error, and the t-value for each curve. Presently the selection of the optimum pavement performance curve is based on the R-squared value.

- Each Model function generates two graph sheets; one without jittered data points and the other with jittered data points. While the non-jittered data format displays only one point in case of multiple occurrences at the same location on the chart, the jittered data format displaces each of those multiple points by an insignificant amount in such a way that all of these points (having the exact same coordinates) appear to be distinct points on the plot.

  This feature gives a better idea about the actual number of data points (n) that constitute the performance curve. The first performance curve generated after every model function is of the non-jittered format and the second performance curve is of the jittered format. Figure D.9 and D.10 show the non-jittered and the jittered version for the same performance curve (THK-A.XLS modeled for BLK.CK using Quadratic model form). Note that while figure D.9 (non-jittered format) looks less cluttered and neat, figure D.10 (jittered format) gives a much better idea about the concentration of data points in certain areas.

- It is possible for the user to create a number of performance curves and evaluate them on the same screen. To print a selected graph sheet, first highlight the graph sheet window and then go to "File" pull-down menu and select "Print Graph Sheet..." option. Alternately, the user can also print the graph sheet by using Ctrl+P.

- Finally, the graph sheets generated during a session can be saved one at a time. To do this, highlight the graph sheet to be saved, go to "File" pull-down menu and select "Save" option [or use Ctrl+S]. The graph sheet will be saved to the selected folder as a *.sgr file.



Date of Analysis: Wed May 27 14:13:11 1998
Family: THK
Index: BLK.CK
Year(s): ALL
Model Type: LINEAR
Analysis Method: GQ
Forced Endpoint: None

25TH PERCENTILE
Coefficient Estimates:
Value Std. Error t value Pr(>|t|)
1 -0.031 0.005 -6.382 0
R-Squared = 0.538

50TH PERCENTILE
Coefficient Estimates:
Value Std. Error t value Pr(>|t|)
1 $\boxed{-0.005}$ 0.002 -2.311 0.027
R-Squared = 0.132

parameter 1

75TH PERCENTILE
Coefficient Estimates:
Value Std. Error t value Pr(>|t|)
1 -0.002 0.001 -1.702 0.098
R-Squared = 0.076

Figure D.6 Linear Performance Model for the Block Cracking Index of the Thick Asphalt with AC Overlay (THK-A) Family.

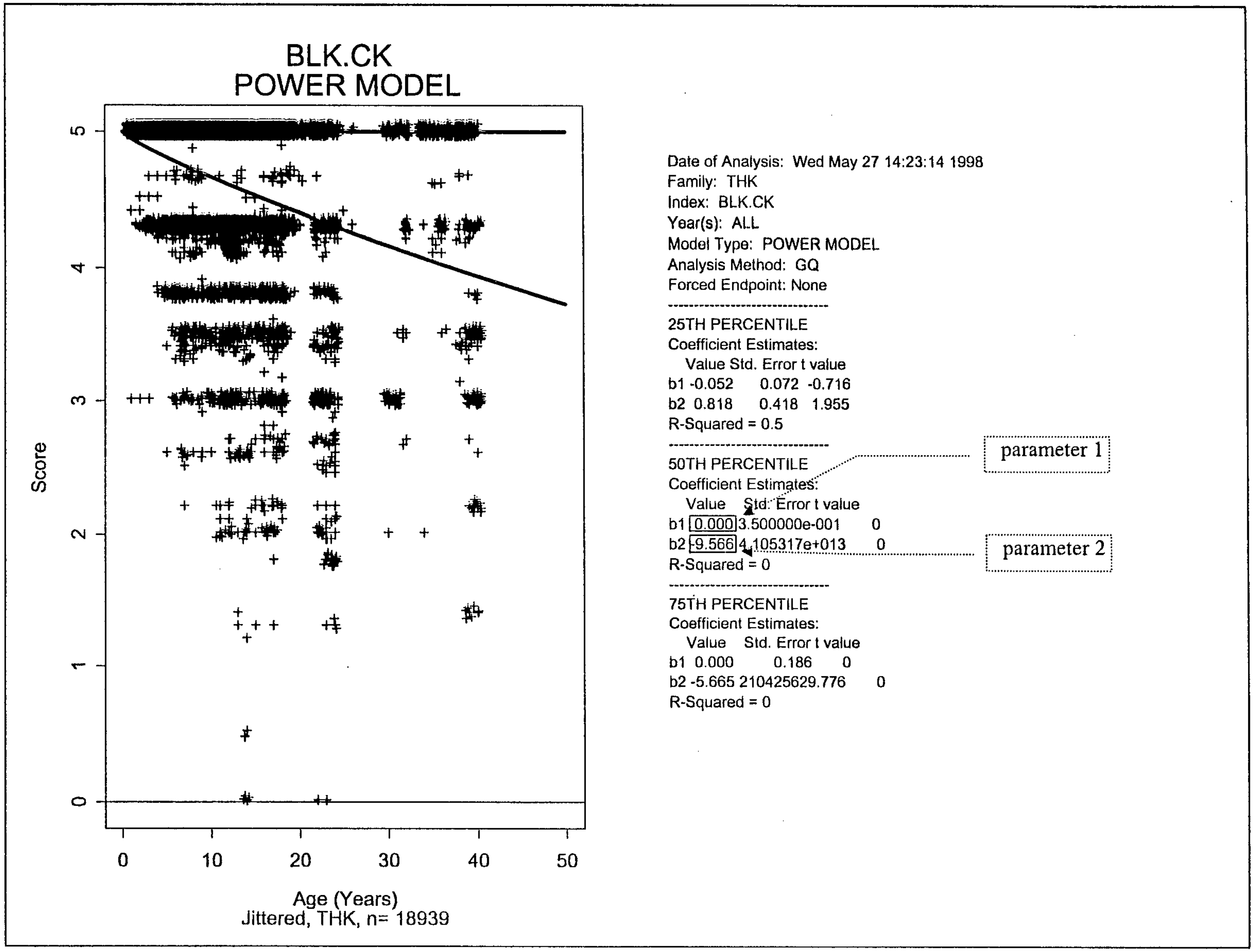
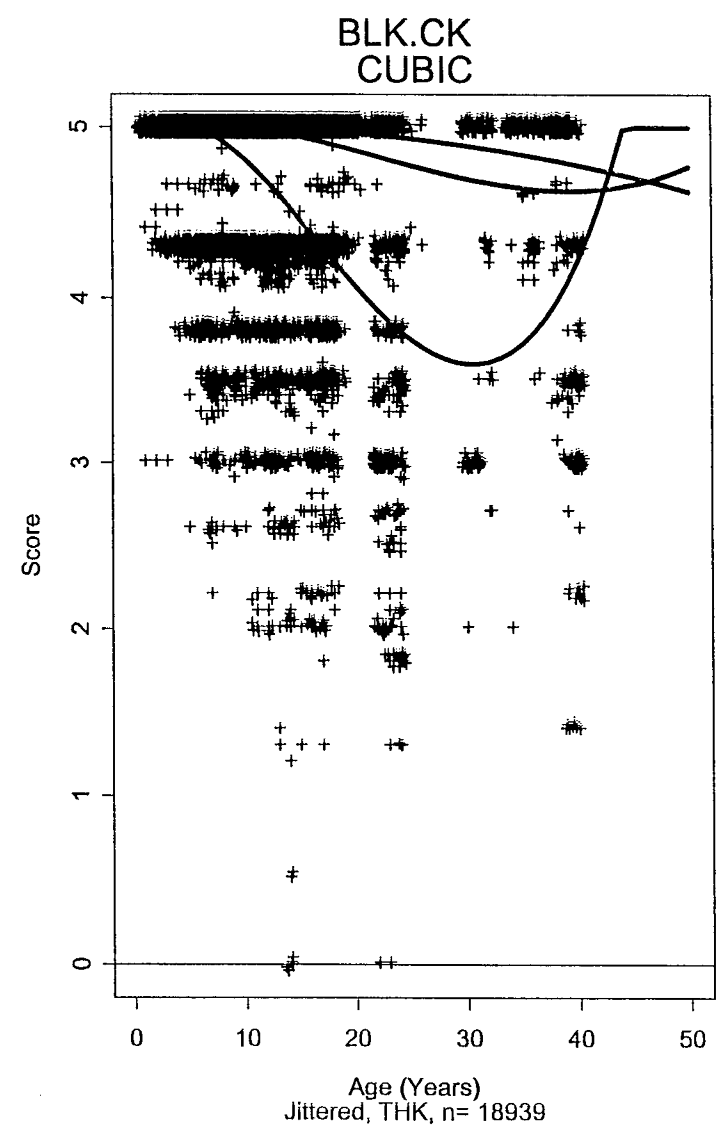


Figure D.7 Power Performance Model for the Block Cracking Index of the Thick Asphalt with AC Overlay (THK-A) Family.



Date of Analysis: Wed May 27 14:32:59 1998
Family: THK
Index: BLK.CK
Year(s): ALL
Model Type: CUBIC
Analysis Method: GQ
Forced Endpoint: None

25TH PERCENTILE
Coefficient Estimates:

	Value	Std. Error	t value	Pr(>|t|)
age	0.036	0.024	1.513	0.140
I(age^2)	-0.007	0.002	-2.891	0.007
I(age^3)	0.000	0.000	2.826	0.008

R-Squared = 0.631

50TH PERCENTILE
Coefficient Estimates:

	Value	Std. Error	t value	Pr(>|t|)
age	$\boxed{0.012}$	0.011	1.093	0.282
I(age^2)	$\boxed{-0.001}$	0.001	-1.247	0.221
I(age^3)	$\boxed{0.000}$	0.000	0.921	0.363

R-Squared = 0.242

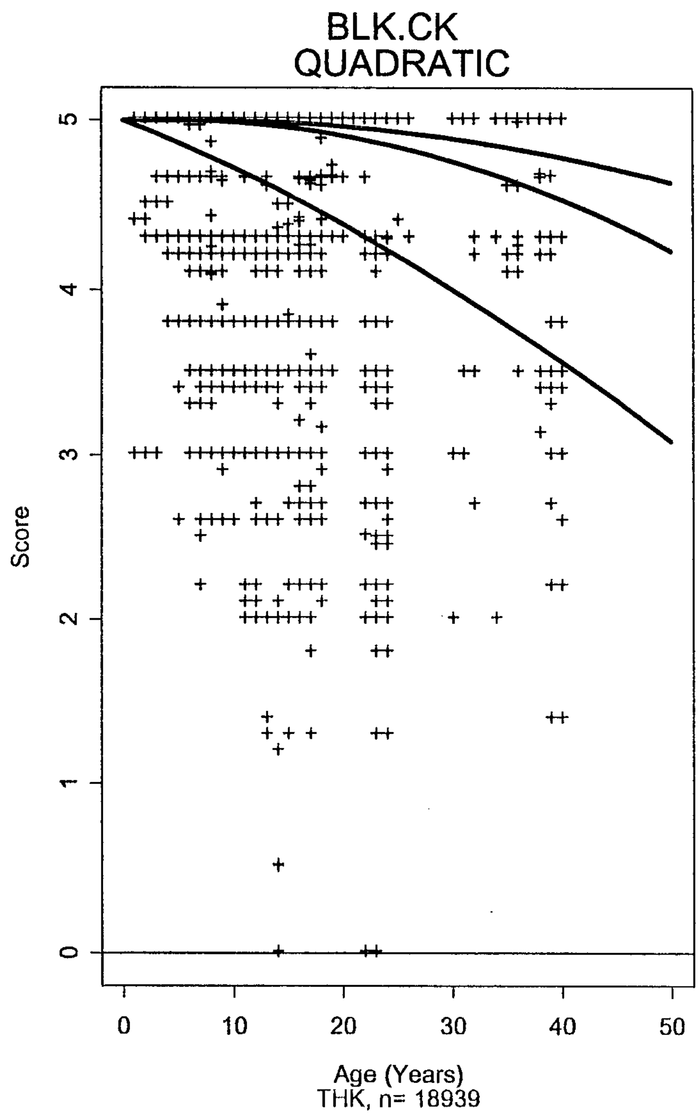
parameter 1
parameter 2
parameter 3

75TH PERCENTILE
Coefficient Estimates:

	Value	Std. Error	t value	Pr(>|t|)
age	0.002	0.006	0.321	0.750
I(age^2)	0.000	0.001	-0.304	0.763
I(age^3)	0.000	0.000	-0.020	0.984

R-Squared = 0.166

Figure D.8 Cubic Performance Model for the Block Cracking Index of the Thick Asphalt with AC Overlay (THK-A) Family.



Date of Analysis: Wed May 27 14:37:46 1998
Family: THK
Index: BLK.CK
Year(s): ALL
Model Type: QUADRATIC
Analysis Method: GQ
Forced Endpoint: None

25TH PERCENTILE
Coefficient Estimates:

	Value	Std. Error	t value	Pr(>|t|)
age	-0.026	0.01	-2.462	0.019
I(age^2)	0.000	0.00	-0.565	0.576

R-Squared = 0.542

50TH PERCENTILE
Coefficient Estimates:

	Value	Std. Error	t value	Pr(>|t|)
age	$\boxed{0.003}$	0.004	0.622	0.538
I(age^2)	$\boxed{0.000}$	0.000	-1.980	0.056

R-Squared = 0.222

parameter 1

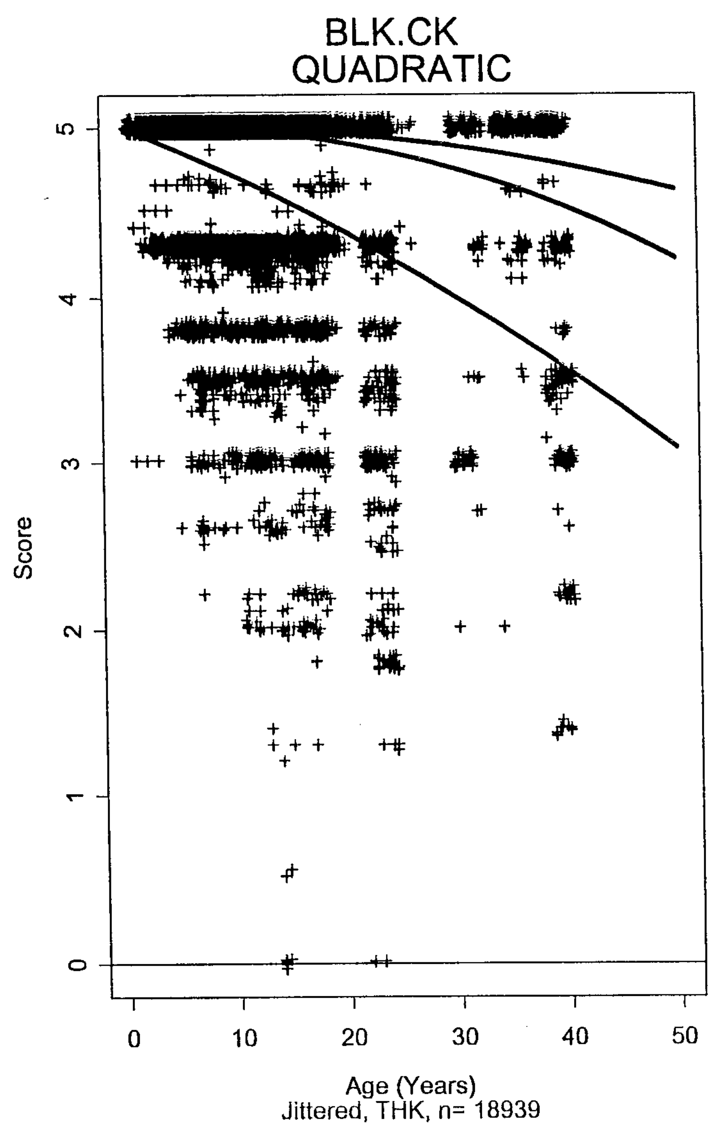
parameter 2

75TH PERCENTILE
Coefficient Estimates:

	Value	Std. Error	t value	Pr(>|t|)
age	0.002	0.002	0.864	0.393
I(age^2)	0.000	0.000	-1.915	0.064

R-Squared = 0.166

Figure D.9 Quadratic (non-jittered) Model for the Block Cracking Index of the Thick Asphalt with AC Overlay (THK-A) family.



Date of Analysis: Wed May 27 14:37:46 1998
Family: THK
Index: BLK.CK
Year(s): ALL
Model Type: QUADRATIC
Analysis Method: GQ
Forced Endpoint: None

25TH PERCENTILE
Coefficient Estimates:

	Value	Std. Error	t value	Pr(>|t|)
age	-0.026	0.01	-2.462	0.019
I(age^2)	0.000	0.00	-0.565	0.576

R-Squared = 0.542

50TH PERCENTILE
Coefficient Estimates:

	Value	Std. Error	t value	Pr(>|t|)
age	0.003	0.004	0.622	0.538
I(age^2)	0.000	0.000	-1.980	0.056

R-Squared = 0.222

parameter 1

parameter 2

75TH PERCENTILE
Coefficient Estimates:

	Value	Std. Error	t value	Pr(>|t|)
age	0.002	0.002	0.864	0.393
I(age^2)	0.000	0.000	-1.915	0.064

R-Squared = 0.166

Figure D.10 Quadratic Performance Model for the Block Cracking Index of the Thick Asphalt with AC Overlay (THK-A) family.

D.4.3.1 Selection of Appropriate Pavement Performance Curve

Once all the four model types have been evaluated it is up to the user to select the performance curve that best represents the pavement deterioration trend expected for the pavement family and the distress condition index under consideration. Important issues to be considered while selecting a pavement performance curve are:

1. Engineering judgment dictates that a pavement performance curve should always exhibit a downward trend. In other words pavements are expected to always deteriorate with age. Depending upon an individual agency and its' policies, performance curves that "flatten" (no change in condition) over a period of time may be acceptable but performance curves should not be allowed to slope upwards with increasing age. If regression analyses results in such performance curves, these curves should be rejected.

2. Generally models of the quadratic, power and cubic form are preferred over models having a linear form because these are more representative of actual pavement deterioration trends.

3. Once all acceptable performance curves have been identified it is best to select the performance curve that has the highest R-squared value for the 50^{th} quantile curve.

4. The final decision regarding the selection of a pavement performance curve should always be supported by sound engineering judgment and expert opinion. A performance curve having a higher R-squared value may be rejected for a curve having a lesser R-squared value if the latter curve is favorable due to both engineering judgment and expert opinion. Rules formulated (for this project) for selection of a performance curve, in case of multiple options, are discussed in the main report.

From among the four example models demonstrated here (figure D.6 through D.10) it is clear that the cubic model is not acceptable as it shows a distinct upward trend. Between the quadratic model and the power model the quadratic model seems to exhibit a more agreeable pavement deterioration trend (shape of curve). Since other model options are available the linear model need not be considered. Still none of the models have a reasonable terminal age and hence we need to introduce a forced endpoint in to the regression analysis (section D.4.4) and constrain the models. But if the selected pavement performance model is found to be perfectly satisfactory for use in the pavement management system, the next step is to convert the performance curve into an equation that can be used by the pavement management system.

D.4.3.2 Equations for Pavement Performance Curves without Forced End Points

The purpose of the statistical analysis procedure is to obtain an equation that can be used to predict pavement performance. Here we shall discuss how to form an equation for each of the four model types. Note that all of these plots (figures D.6 to D.10) are without forced endpoints. The equations for performance curves with forced endpoint are slightly different and will be discussed in section D.4.4.2.

Linear Performance Model Equation without Forced End Point

Figure D.6 presents a linear performance model. The linear equation for predicting the pavement performance index is expressed as:

$$\text{SCORE} = 5 + [\ (\text{parameter 1}) \times (\text{age})\ ]$$

where parameter 1 is the value for the 50^{th} quantile curve marked on figure D.6. For this particular performance model the value of parameter 1 is –0.005 (negative).

Power Performance Model Equation without Forced End Point

Figure D.7 presents a power performance model. The power equation for predicting the pavement performance index is expressed as:

$$\text{SCORE} = 5 + [\ (\text{parameter 1}) \times (\text{age})^{(\text{parameter 2})}\ ]$$

where parameter 1 and parameter 2 are the values for the 50^{th} quantile curve marked on figure D.7. For this particular performance model the value for parameter 1 is 0 and the value for parameter 2 is –9.566 (negative).

Cubic Performance Model Equation without Forced End Point

Figure D.8 presents a cubic performance model. The cubic equation for predicting the pavement performance index is expressed as:

$$\text{SCORE} = 5 + [\ (\text{parameter 1}) \times (\text{age})\ ] + [\ (\text{parameter 2}) \times (\text{age})^2\ ] + [\ (\text{parameter 3}) \times (\text{age})^3\ ]$$

where parameter 1, parameter 2, and parameter 3 are the values for the 50^{th} quantile curve marked on figure D.8. For this particular performance model the value for parameter 1 is 0.012, the value for parameter 2 is –0.001 (negative) and the value for parameter 3 is 0.000.

Quadratic Performance Model Equation without Forced End Point

Figure D.10 presents a quadratic performance model. The quadratic equation for predicting the pavement performance index is expressed as:

$$\text{SCORE} = 5 + [\ (\text{parameter 1}) \times (\text{age})\ ] + [\ (\text{parameter 2}) \times (\text{age})^2\ ]$$

where parameter 1 and parameter 2 are the values for the 50^{th} quantile curve marked on figure D.10. For this particular performance model the value for parameter 1 is 0.003 and the value for parameter 2 is 0.000.

D.4.4 Performance Curves Using Forced End Points

Stopgap maintenance activities, applied to maintain pavement condition at an acceptable level until rehabilitation can be applied, tend to artificially "flatten" pavement performance curves at particular condition levels. This phenomenon has been discussed earlier in the report accompanying this Technical Memorandum. PPMT allows the user to select an end point (age on the x-axis) through which the performance curve will be forced to pass, i.e. the performance curve will intersect the x-axis at the selected end point. Hence this point is referred to as a forced end point. Figures D.6 through D.10 make it clear that none of the model forms give a reasonable trend for pavement deterioration. All of these curves have a tendency to "over-predict" pavement condition and hence it becomes necessary to select a reasonable age (at which the particular distress condition index can be expected to reach 0.00) and force the performance curve to intersect the x-axis at that age.

Once the appropriate performance curve has been selected for the pavement family and the distress condition index under consideration, and if that curve still does not terminate at a reasonable age, it is required to introduce a forced end point in the regression analysis. An iterative process is used to select the forced end point that is best suited to the pavement condition data. The forced end point selected after this iterative process is referred to as the optimum forced end point.

D.4.4.1 Determination of Optimum Forced End Point

The procedure for determining the optimum forced end point involves the following steps:

1. Identify the model form for which the optimum forced end point is to be determined. In the demonstration example (figures D.6 through D.10) the quadratic model and the power model both seem to exhibit a reasonable pavement deterioration trend with the quadratic model form having a more agreeable shape. Thus, the optimum forced endpoint for the quadratic model will be determined.

2. Use the PPMT to generate performance curves of the quadratic form but constraining them by entering values in the "Forced Endpoint" box (figure D.5). Starting with a forced end point at a lower limit of age say 10 years, generate curves for forced end points at 5-year increments up to a upper limit of age say 60 years. In other words, use forced endpoints of 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60. Record the R-squared value of the 50th quantile curve obtained for the performance model at each forced end point. For the demonstration example, the R-squared values obtained after the first iteration are shown in table D.1.

Table D.1 R-squared values obtained for forced end point models after first iteration.

Thick Asphalt with AC Overlay Pavement Family: Block Cracking Index Performance Model											
Forced Endpoint	10	15	20	25	**30**	35	40	45	50	55	60
R^2 [Quadratic Model]	0.417	0.441	0.485	0.577	**0.675**	0.539	0.302	0.384	0.438	0.470	0.482

Here we see that the maximum R-squared value is obtained at a (forced) terminal age of 30 years. Hence, at the end of the first iteration the tentative optimum forced endpoint is 30. But still the forced end point that would give the highest R-squared value could lie anywhere between age 25 and age 35. The absolute optimum forced endpoint is to be determined in the second iteration.

3. Use the PPMT to again generate a series of performance curves, this time constraining the models to forced endpoints around ± 4 years (for a 5-year initial increment) the tentative optimum forced endpoint obtained after the first iteration. For the demonstration example, the R-squared values obtained after the second iteration are shown in table D.2.

Table D.2 R-squared values obtained for forced end point models after second iteration.

Thick Asphalt with AC Overlay Pavement Family: Block Cracking Index Performance Model									
Forced Endpoint	26	27	28	**29**	30	31	32	33	34
R^2 [Quadratic Model]	0.612	0.643	0.670	**0.694**	0.675	0.653	0.628	0.646	0.590

At the end of the second iteration the optimum forced endpoint is determined to be at age 29 (maximum R-squared value of 0.694). Hence the performance model selected is a quadratic model form constrained at a forced end point of 29 years.

4. If desired, a similar iterative process can be carried out for another feasible model form, say the power model. After the optimum forced end point has been determined, the selection between the two model options can be based on the model that provides a higher R-squared value and/or exhibits a better pavement deterioration trend.

Figure D.11 shows the constrained Block Cracking Index quadratic model for the Thick Asphalt with AC Overlay pavement family. The model is constrained at age 29 years (from table D.2).

D.4.4.2 Equations for Pavement Performance Curves with Forced End Points

Similar to unconstrained pavement performance models, the final aim of developing constrained pavement performance models is to obtain an equation that can be used to predict pavement performance. Here we shall discuss how to form an equation for each of the four constrained model types (Linear, Power, Cubic, and Quadratic) presented as figures D.11 through D.14. Note that the equations for constrained (with forced endpoint) models are slightly different from the equations for unconstrained (without forced endpoint) models.

Linear Performance Model Equation with Forced End Point

The linear equation for predicting the pavement performance index using a model form is expressed as:

$$SCORE = 5 - [\ \{ 5 \times (age)\} / (E)\ ]$$

where E is the value of the optimum forced endpoint selected for that particular model as presented in figure D.11.

Power Performance Model Equation with Forced End Point

The power equation for predicting the pavement performance index using a model form is expressed as:

$$\text{SCORE} = 5 \times [\, 1 - \exp\{\, (\text{parameter } 1) \times (\log(\text{age}/E))\, \}\,]$$

where parameter 1 is the value for the 50^{th} quantile curve as marked on figure D.12 and E is the value of the optimum forced endpoint selected for that particular model.

Cubic Performance Model Equation with Forced End Point

The cubic equation for predicting the pavement performance index using a model form is expressed as:

$$\text{SCORE} = 5 \times [\, 1 - (\text{age}/E)^3\,] + [\, (\text{parameter } 1) \times (\text{age}) \times (1 - (\text{age}/E)^2)\,] + [\, (\text{parameter } 2) \times (\text{age})^2 \times (1 - (\text{age}/E))\,]$$

where parameter 1 and parameter 2 are the values for the 50^{th} quantile curve as marked on figure D.13 and E is the value of the optimum forced endpoint selected for that particular model.

Quadratic Performance Model Equation with Forced End Point

The quadratic equation for predicting the pavement performance index using a model form is expressed as:

$$\text{SCORE} = 5 \times [\, 1 - (\text{age}/E)^2\,] + [\, (\text{parameter } 1) \times (\text{age}) \times (1 - (\text{age}/E))\,]$$

where parameter 1 is the value for the 50^{th} quantile curve marked on figure D.14 and E is the value of the optimum forced endpoint selected for that particular model.

For the demonstration example the final pavement performance model equation is:

Pavement Family : Thick Asphalt pavements with AC Overlay
Condition Index : Block Cracking
Model Form : Constrained Quadratic Model

Model Equation : $\text{SCORE} = 5 \times [\, 1 - (\text{age}/29)^2\,] + [\, (0.135) \times (\text{age}) \times (1 - (\text{age}/29))\,]$

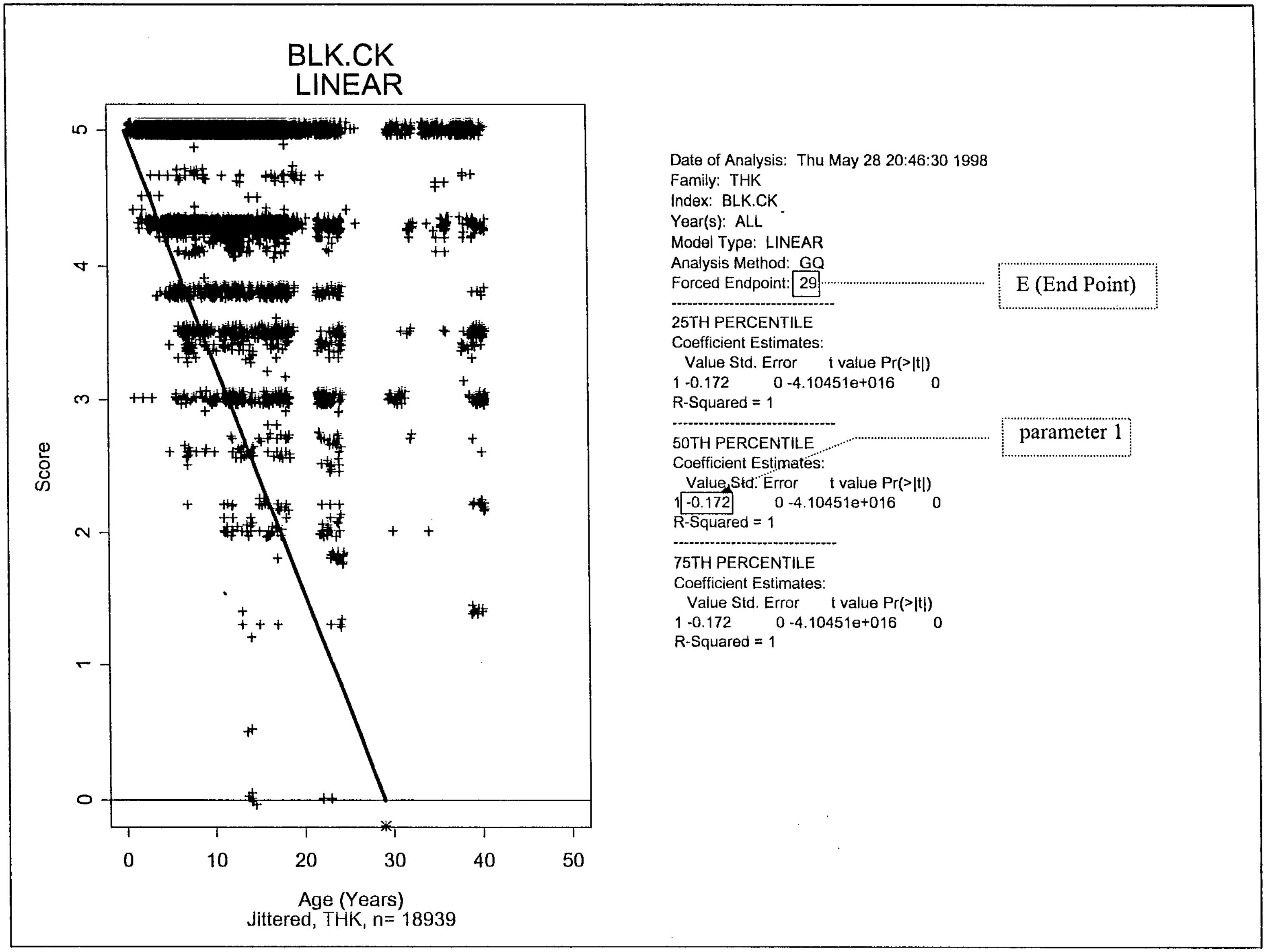


Figure D.11 Linear Model (Forced End Point) for the Block Cracking Index of the Thick Asphalt with AC Overlay (THK-A) family.

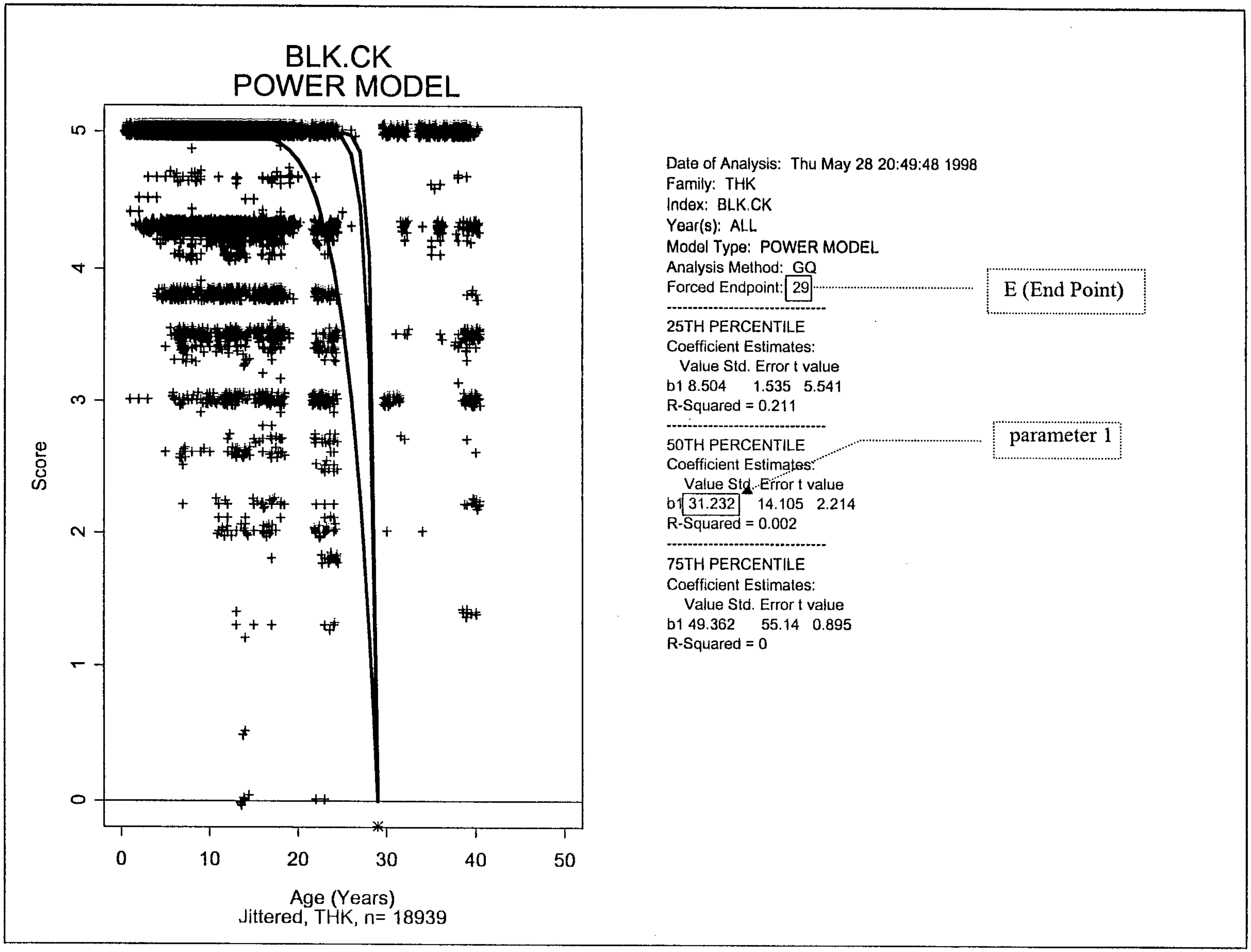


Figure D.12 Power Model (Forced End Point) for the Block Cracking Index of the Thick Asphalt with AC Overlay (THK-A) family.

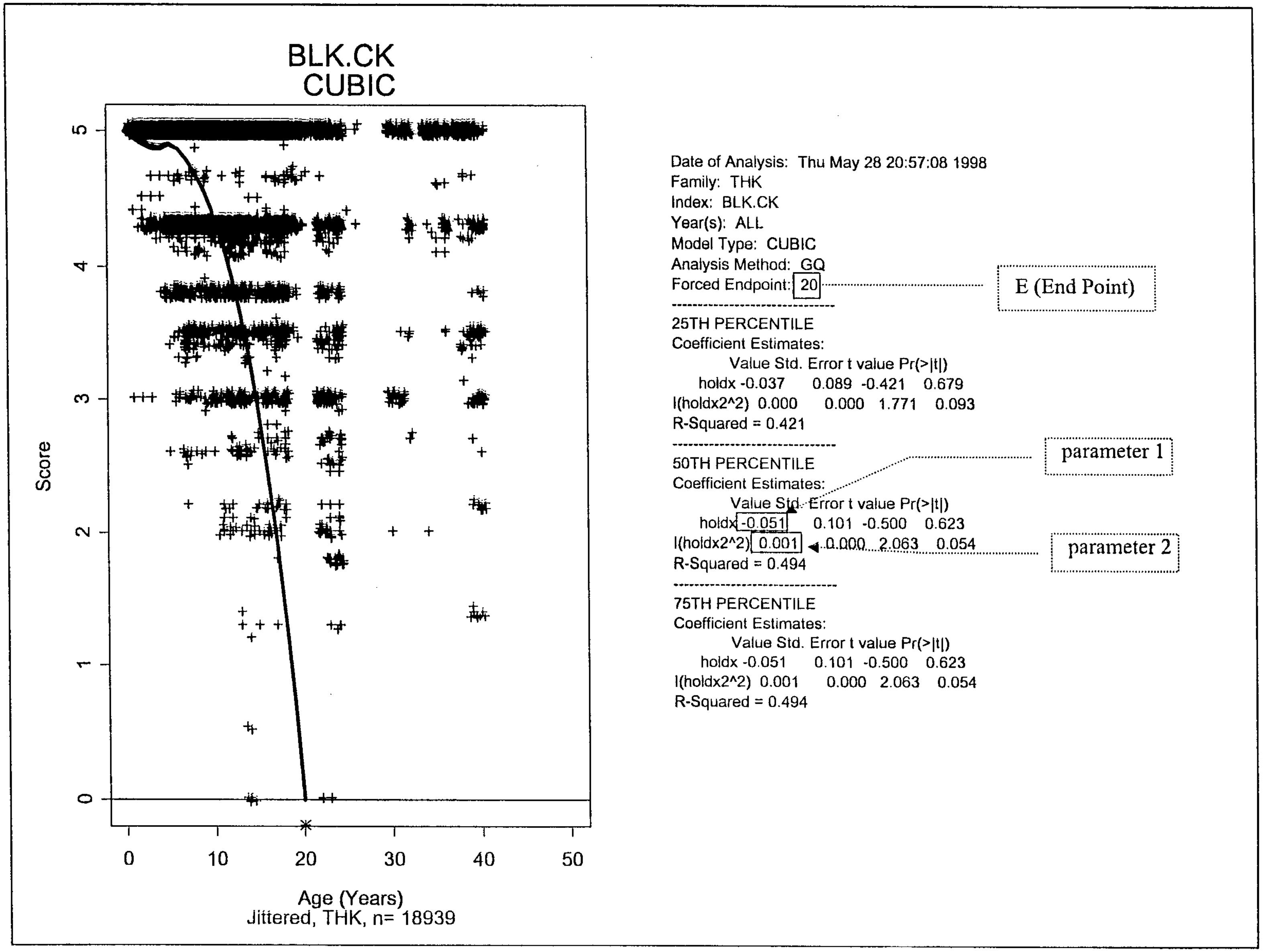


Figure D.13 Cubic Model (Forced End Point) for the Block Cracking Index of the Thick Asphalt with AC Overlay (THK-A) family.

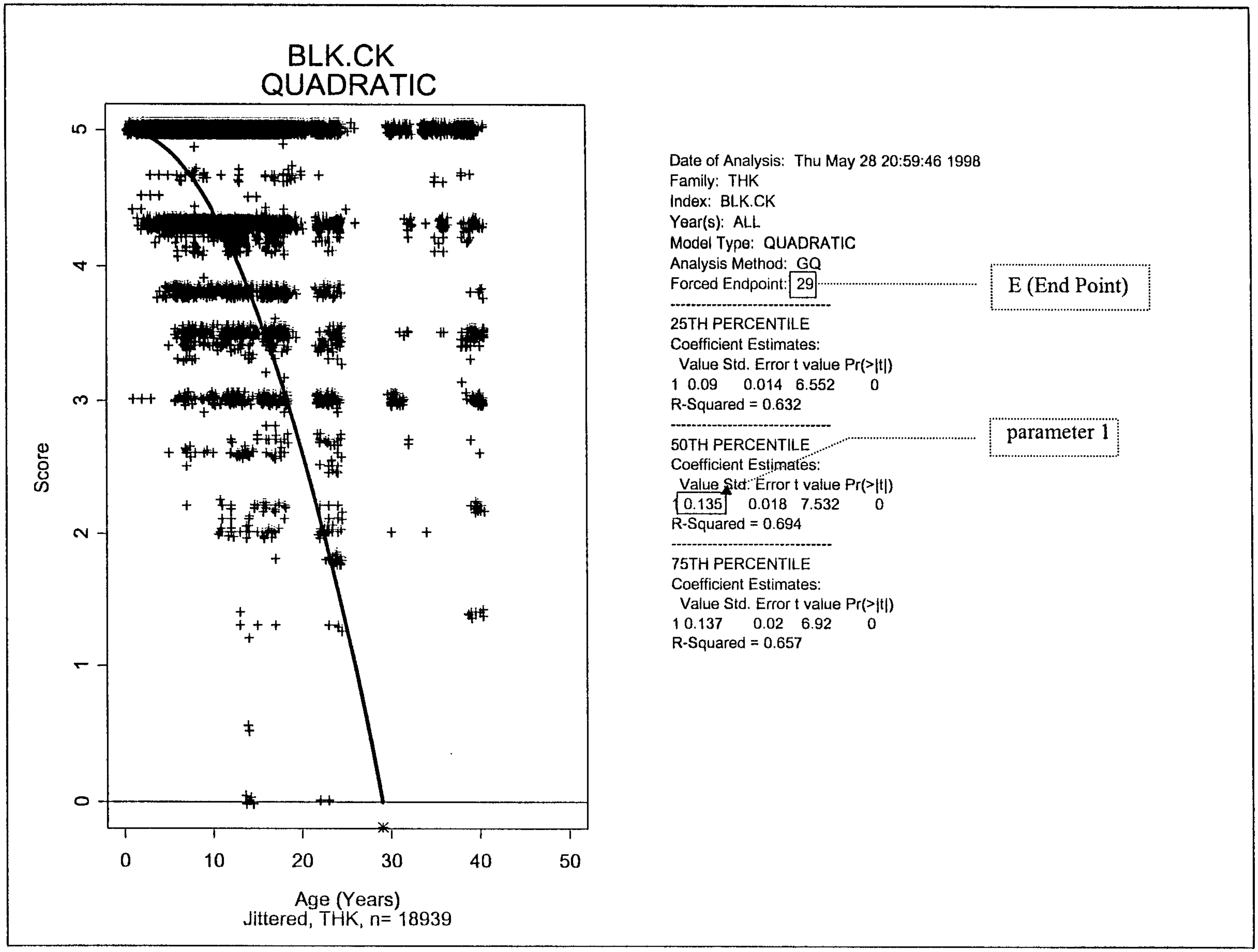


Figure D.14 Quadratic Model (Forced End Point) for the Block Cracking Index of the Thick Asphalt with AC Overlay (THK-A)

D.4.4.3 Limitation of the Optimum Forced End Point Method

The forced end point method is not always required but may be used if the data does not reflect an acceptable downward trend for pavement deterioration, either due to stop-gap maintenance activities or even due to inaccurate field data collection practices. If the forced end point method is used it is important to note that, for such performance models of any form, the PPMT program has been designed to force the regression equation through the forced endpoint and then calculate the statistics (R-squared) on the fit of the line to the data points on the left-hand side of the forced endpoint. In other words, any data points to the right of the forced endpoint are not considered in the curve fitting statistics. Hence constrained performance models should be subjected to serious scrutiny, using engineering judgment and expert opinion, before they are accepted for use by the pavement management system.

D.5 Conclusion

Pavement performance curves developed through the procedure described in this Technical Memorandum depend heavily, for their validity and accuracy, on the amount and accuracy of pavement condition data available in the database. Any increase in the amount of condition data used for developing a performance model will help in further refining that particular model to better represent the actual trend of pavement deterioration for that pavement family. Hence, once the performance models have been developed based on presently available data, it is recommended that these models be updated following each condition survey carried out by the agency. After appending the new condition data to the old existing data, the same procedures as described in this Technical Memorandum, for creating the pavement performance models, are to be used for updating the models.